

WHAT IS CLAIMED IS:

- 1           1.       A method for maximum a posteriori (MAP) decoding of an input  
2 information sequence based on a first information sequence received through a channel,  
3 comprising:  
4           iteratively generating a sequence of one or more decode results starting with an  
5 initial decode result; and  
6           outputting one of adjacent decode results as a decode of the input information  
7 sequence if the adjacent decode results are within a compare threshold.
- 1           2.       The method of claim 1, wherein the iteratively generating comprises:  
2           a. generating the initial decode result as a first decode result;  
3           b. generating a second decode result based on the first decode result and a model  
4 of the channel;  
5           c. comparing the first and second decode results;  
6           d. replacing the first decode result with the second decode result; and  
7           e. repeating b-d if the first and second decode results are not within the compare  
8 threshold.
- 1           3.       The method of claim 2, wherein the generating a second decode result  
2 comprises searching for a second information sequence that maximizes a value of an  
3 auxiliary function.
- 1           4.       The method of claim 3, wherein the auxiliary function is based on the  
2 expectation maximization (EM) algorithm.
- 1           5.       The method of claim 4, wherein the model of the channel is a Hidden  
2 Markov Model (HMM) having an initial state probability vector  $\pi$  and probability density  
3 matrix (PDM) of  $P(X,Y)$ , where  $X \in \mathbf{X}$ ,  $Y \in \mathbf{Y}$  and elements of  $P(X,Y)$ ,  
4  $p_{ij}(X,Y) = \Pr(j,X,Y \mid i)$ , are conditional probability density functions of an information  
5 element  $X$  of the second information sequence that corresponds to a received element  $Y$   
6 of the first information sequence after the HMM transfers from a state  $i$  to a state  $j$ , the  
7 auxiliary function being expressed as:

8  $Q(X_1^T, X_{1,p}^T) = \sum_z \Psi(z, X_1^T, Y_1^T) \log(\Psi(z, X_1^T, Y_1^T))$ , where  $p$  is a number of  
 9 iterations,  $\Psi(z, X_1^T, Y_1^T) = \pi_{i_0} \prod_{t=1}^T p_{i_{t-1}i_t}(X_t, Y_t)$ ,  $T$  is a number of information elements  
 10 in a particular information sequence,  $z$  is a HMM state sequence  $i_0^T$ ,  $\pi_{i_0}$  is the probability  
 11 of an initial state  $i_0$ ,  $X_1^T$  is the second information sequence,  $X_{1,p}^T$  is a second information  
 12 sequence estimate corresponding to a  $p$ th iteration, and  $Y_1^T$  is the first information  
 13 sequence.

1 6. The method of claim 5, wherein the auxiliary function is expanded to be:

$$2 \quad Q(X_1^T, X_{1,p}^T) = \sum_{t=1}^T \sum_{i=1}^n \sum_{j=1}^n \gamma_{t,ij}(X_{1,p}^T) \log(p_{ij}(X_t, Y_t)) + C$$

3 where  $C$  does not depend on  $X_1^T$  and

$$4 \quad \gamma_{t,ij}(X_{1,p}^T) = \alpha_i(X_{1,p}^{t-1}, Y_1^{t-1}) p_{ij}(X_{t,p}, Y_t) \beta_j(X_{t+1,p}^T, Y_{t+1}^T)$$

5 where  $\alpha_i(X_{1,p}^t, Y_1^T)$  and  $\beta_j(X_{t+1,p}^T, Y_{t+1}^T)$  are the elements of forward and backward  
 6 probability vectors defined as

$$7 \quad \alpha(X_1^t, Y_1^T) = \pi \prod_{i=1}^t P(X_i, Y_i), \text{ and } \beta(X_1^T, Y_1^T) = \prod_{j=t}^T P(X_j, Y_j) \mathbf{1}, \quad \pi \text{ is an}$$

8 initial probability vector,  $\mathbf{1}$  is the column vector of ones.

1 7. The method of claim 6, wherein a source of an encoded sequence is a  
 2 trellis code modulator (TCM), the TCM receiving a source information sequence  $I_1^T$  and  
 3 outputting  $X_1^T$  as an encoded information sequence that is transmitted, the TCM defining  
 4  $X_t = g_t(S_t, I_t)$  where  $X_t$  and  $I_t$  are the elements of  $X_1^T$  and  $I_1^T$  for each time  $t$ , respectively,  $S_t$   
 5 is a state of the TCM at  $t$ , and  $g_t(\cdot)$  is a function relating  $X_t$  to  $I_t$  and  $S_t$ , the method  
 6 comprising:

7 generating, for iteration  $p+1$ , a source information sequence estimate  $I_{1,p+1}^T$  that  
 8 corresponds to a sequence of TCM state transitions that has a longest cumulative distance  
 9  $L(S_{t-1})$  at  $t = 1$  or  $L(S_0)$ , wherein a distance for each of the TCM state transitions is  
 10 defined by  $L(S_t) = L(S_{t+1}) + m(\hat{I}_{t+1}(S_{t+1}))$  for the TCM state transitions at each  $t$  for

11  $t = 1, \dots, T$  and the cumulative distance is the sum of  $m(\hat{I}_t(S_t))$  for all  $t$ ,  $m(\hat{I}_t(S_t))$  being  
 12 defined as

$$13 \quad m(\hat{I}_t(S_t)) = \sum_{i=1}^{n_c} \sum_{j=1}^{n_c} \gamma_{t,ij} (I_{i,p}^T) \log p_{c,ij} (Y_t | X_t(S_t)), \text{ for each } t = 1, 2, \dots, T, \text{ where}$$

14  $X_t(S_t) = g_t(S_t, \hat{I}_t(S_t))$ ,  $n_c$  is a number of states in an HMM of the channel and  
 15  $p_{c,ij}(Y_t | X_t(S_t))$  are channel conditional probability density functions of  $Y_t$  when  $X_t(S_t)$  is  
 16 transmitted by the TCM,  $I_{i,p+1}^T$  being set to a sequence of  $\hat{I}_t$  for all  $t$ .

1 8. The method of claim 7, wherein for each  $t = 1, 2, \dots, T$ , the method  
 2 comprises:

3 generating  $m(\hat{I}_t(S_t))$  for each possible state transition of the TCM;

4 selecting state trajectories that correspond to largest

5  $L(S_t) = L(S_{t+1}) + m(\hat{I}_{t+1}(S_{t+1}))$  for each state as survivor state trajectories; and

6 selecting  $\hat{I}_t(S_t)$ s that correspond to the selected state trajectories as  $I_{t,p+1}(S_t)$ .

1 9. The method of claim 8, further comprising:

2 a. assigning  $L(S_T) = 0$  for all states at  $t = T$ ;

3 b. generating  $m(\hat{I}_t(S_t))$  for all state transitions between states  $S_t$  and all possible  
 4 states  $S_{t+1}$ ;

5 c. selecting state transitions between the states  $S_t$  and  $S_{t+1}$  that have a largest

6  $L(S_t) = L(S_{t+1}) + m(\hat{I}_{t+1}(S_{t+1}))$  and  $\hat{I}_{t+1}(S_{t+1})$  that correspond to the selected state  
 7 transitions;

8 d. updating the survivor state trajectories at states  $S_t$  by adding the selected state  
 9 transitions to the corresponding survivor state trajectories at state  $S_{t+1}$ ;

10 e. decrementing  $t$  by 1;

11 f. repeating b-e until  $t = 0$ ; and

12 g. selecting all the  $\hat{I}_t(S_t)$  that correspond to a survivor state trajectory that  
 13 corresponding to a largest  $L(S_t)$  at  $t = 0$  as  $I_{i,p+1}^T$ .

1 10. The method of claim 6, wherein the channel is modeled as  $P_c(Y | X) =$   
 2  $P_c B_c(Y | X)$  where  $P_c$  is a channel state transition probability matrix and  $B_c(Y | X)$  is a

3 diagonal matrix of state output probabilities, the method comprising for each  $t = 1, 2, \dots$ ,  
 4 T:

5 generating  $\gamma_{t,i}(I_{l,p}^T) = \alpha_i(Y_t^T | I_{l,p}^T) \beta_i(Y_{t+1}^T | I_{t+1,p}^T)$ ;

6 selecting an  $\hat{I}_t(S_t)$  that maximizes  $L(S_t) = L(S_{t+1}) + m(\hat{I}_{t+1}(S_{t+1}))$ , where

7  $m(\hat{I}_t(S_t))$  is defined as

8 
$$m(\hat{I}_t(S_t)) = \sum_{i=1}^{n_c} \gamma_{t,i}(I_{l,p}^T) \beta_j(Y_t | X_t(S_t)),$$
  $n_c$  being a number of states in an HMM of

9 the channel;

10 selecting state transitions between states  $S_t$  and  $S_{t+1}$  that corresponds to a largest

11  $L(S_t) = L(S_{t+1}) + m(\hat{I}_{t+1}(S_{t+1}))$ ; and

12 forming survivor state trajectories by connecting selected state transitions.

1 11. The method of claim 10, further comprising:

2 selecting  $\hat{I}_t(S_t)$  that corresponds to a survivor state trajectory at  $t = 0$  that has the

3 largest  $L(S_t)$  as  $I_{l,p+1}^T$  for each  $p$ th iteration;

4 comparing  $I_{l,p}^T$  and  $I_{l,p+1}^T$ ; and

5 outputting  $I_{l,p+1}^T$  as the second decode result if  $I_{l,p}^T$  and  $I_{l,p+1}^T$  are within the

6 compare threshold.

1 12. A maximum a posteriori (MAP) decoder that decodes a transmitted

2 information sequence using a received information sequence received through a channel,

3 comprising:

4 a memory; and

5 a controller coupled to the memory, the controller iteratively generating a

6 sequence of one or more decode results starting with an initial decode result, and

7 outputting one of adjacent decode results as a decode of the input information sequence if

8 the adjacent decode results are within a compare threshold.

1 13. The decoder of claim 12, wherein the controller:

2 a. generates the initial decode result as a first decode result;

3 b. generates a second decode result based on the first decode result and a model

4 of the channel;

5 c. compares the first and second decode results;  
 6 d. replaces the first decode result with the second decode result; and  
 7 e. repeats b-d until the first and second decode result are not within the compare  
 8 threshold.

1 14. The decoder of claim 13, wherein the controller searches for information  
 2 sequence that maximizes a value of an auxiliary function.

1 15. The decoder of claim 14, wherein the auxiliary function is based on  
 2 expectation maximization (EM).

1 16. The decoder of claim 15, wherein the model of the channel is a Hidden  
 2 Markov Model (HMM) having an initial state probability vector  $\pi$  and probability density  
 3 matrix (PDM) of  $P(X,Y)$ , where  $X \in \mathbf{X}$ ,  $Y \in \mathbf{Y}$  and elements of  $P(X,Y)$ ,  
 4  $p_{ij}(X,Y) = \Pr(j,X,Y | i)$ , are conditional probability density functions of an information  
 5 element  $X$  of the second information sequence that corresponds to a received element  $Y$   
 6 of the first information sequence after the HMM transfers from a state  $i$  to a state  $j$ , the  
 7 auxiliary function being expressed as:

8  $Q(X_1^T, X_{1,p}^T) = \sum_z \Psi(z, X_{1,p}^T, Y_1^T) \log(\Psi(z, X_1^T, Y_1^T))$ , where  $p$  is a number of  
 9 iterations,  $\Psi(z, X_1^T, Y_1^T) = \pi_{i_0} \prod_{t=1}^T p_{i_{t-1}, i_t}(X_t, Y_t)$ ,  $T$  is a number of information elements  
 10 in a particular information sequence,  $z$  is a HMM state sequence  $i_0^T$ ,  $\pi_{i_0}$  is the probability  
 11 of an initial state  $i_0$ ,  $X_1^T$  is the second information sequence,  $X_{1,p}^T$  is a second information  
 12 sequence estimate corresponding to a  $p$ th iteration, and  $Y_1^T$  is the first information  
 13 sequence.

1 17. The decoder of claim 16, wherein the auxiliary function is expanded to be:

$$2 \quad Q(X_1^T, X_{1,p}^T) = \sum_{t=1}^T \sum_{i=1}^n \sum_{j=1}^n \gamma_{t,ij}(X_{1,p}^T) \log(p_{ij}(X_t, Y_t)) + C$$

3 where  $C$  does not depend on  $X_1^T$  and

$$4 \quad \gamma_{t,ij}(X_{1,p}^T) = \alpha_i(X_{1,p}^{t-1}, Y_1^{t-1}) p_{ij}(X_{t,p}, Y_t) \beta_j(X_{1,p}^{t+1}, Y_{t+1}^T)$$

5 where  $\alpha_i(X_{1,p}^t, Y_1^T)$  and  $\beta_j(X_{1,p}^{t+1}, Y_{t+1}^T)$  are the elements of forward and backward  
 6 probability vectors defined as

7  $\alpha(X_1^T, Y_1^T) = \pi \prod_{i=1}^T P(X_i, Y_i)$ , and  $\beta(X_{t+1}^T, Y_{t+1}^T) = \prod_{j=t+1}^T P(X_j, Y_j) \mathbf{1}$ ,  $\pi$  is an initial

8 probability vector,  $\mathbf{1}$  is the column vector of ones.

1 18. The decoder of claim 17, wherein a source of an encoded sequence is a  
 2 trellis code modulator (TCM), the TCM receiving a source information sequence  $I_1^T$  and  
 3 outputting  $X_1^T$  as an encoded information sequence that is transmitted, the TCM defining  
 4  $X_t = g_t(S_t, I_t)$  where  $X_t$  and  $I_t$  are the elements of  $X_1^T$  and  $I_1^T$  for each time  $t$ , respectively,  $S_t$   
 5 is a state of the TCM at  $t$ , and  $g_t(\cdot)$  is a function relating  $X_t$  to  $I_t$  and  $S_t$ , the controller  
 6 generates, for iteration  $p+1$ , an input information sequence estimate  $I_{1,p+1}^T$  that  
 7 corresponds to a sequence of TCM state transitions that has a longest cumulative distance  
 8  $L(S_{t-1})$  at  $t = 1$  or  $L(S_0)$ , wherein a distance for each of the TCM state transitions is  
 9 defined by  $L(S_{t+1}) = L(S_t) + m(\hat{I}_{t+1}(S_{t+1}))$  for the TCM state transitions at each  $t$  for  
 10  $t = 1, \dots, T$  and the cumulative distance is the sum of  $m(\hat{I}_t(S_t))$  for all  $t$ ,  $m(\hat{I}_t(S_t))$  being  
 11 defined as

12 
$$m(\hat{I}_t(S_t)) = \sum_{i=1}^{n_c} \sum_{j=1}^{n_c} \gamma_{t,ij}(I_{1,p}^T) \log p_{c,ij}(Y_t | X_t(S_t)), \text{ for each } t = 1, 2, \dots, T, \text{ where}$$

13  $X_t(S_t) = g_t(S_t, \hat{I}_t(S_t))$ ,  $n_c$  is a number of states in an HMM of the channel and  
 14  $p_{c,ij}(Y_t | X_t(S_t))$  are channel conditional probability density functions of  $Y_t$  when  $X_t(S_t)$  is  
 15 transmitted by the TCM,  $I_{1,p+1}^T$  being set to a sequence of  $\hat{I}_t$  for all  $t$ .

1 19. The decoder of claim 18, wherein for each  $t = 1, 2, \dots, T$ , the controller  
 2 generating  $m(\hat{I}_t(S_t))$  for each possible state transition of the TCM, selecting state  
 3 trajectories that correspond to largest  $L(S_t) = L(S_{t+1}) + m(\hat{I}_{t+1}(S_{t+1}))$  for each state as  
 4 survivor state trajectories, and selecting  $\hat{I}_{t+1}(S_{t+1})$ s that correspond to the selected state  
 5 trajectories as  $I_{t+1,p+1}(S_{t+1})$ .

1 20. The decoder of claim 19, wherein the controller:

- 2 a. assigns  $L(S_T) = 0$  for all states at  $t = T$ ;
- 3 b. generates  $m(\hat{I}_t(S_t))$  for all state transitions between states  $S_t$  and all possible
- 4 states  $S_{t+1}$ ;

- 5 c. selects state transitions between the states  $S_t$  and  $S_{t+1}$  that have a largest  
 6  $L(S_t) = L(S_{t+1}) + m(\hat{I}_{t+1}(S_{t+1}))$  and  $\hat{I}_{t+1}(S_{t+1})$  that correspond to the selected state  
 7 transitions;  
 8 d. updates the survivor state trajectories at states  $S_t$  by adding the selected state  
 9 transitions to the corresponding survivor state trajectories at state  $S_{t+1}$ ;  
 10 e. decrements  $t$  by 1;  
 11 f. repeats b-e until  $t = 0$ ; and  
 12 g. selects all the  $\hat{I}_t(S_t)$  that correspond to a survivor state trajectory that  
 13 corresponding to a largest  $L(S_t)$  at  $t = 0$  as  $I_{1,p+1}^T$ .

1 21. The decoder of claim 20, wherein the channel is modeled as  $P_c(Y|X) =$   
 2  $P_c B_c(Y|X)$  where  $P_c$  is a channel state transition probability matrix and  $B_c(Y|X)$  is a  
 3 diagonal matrix of state output probabilities, for each  $t = 1, 2, \dots, T$ , the controller:

4 generates  $\gamma_{t,i}(I_{1,p}^T) = \alpha_i(Y_t^T | I_{1,p}^T) \beta_i(Y_{t+1}^T | I_{t+1,p}^T)$ ;  
 5 selects an  $\hat{I}_t(S_t)$  that maximizes  $L(S_t) = L(S_{t+1}) + m(\hat{I}_{t+1}(S_{t+1}))$ , where  $m(\hat{I}_t(S_t))$   
 6 is defined as

7 
$$m(\hat{I}_t(S_t)) = \sum_{i=1}^{n_c} \gamma_{t,i}(I_{1,p}^T) \beta_j(Y_t | X_t(S_t)),$$
  $n_c$  being a number of states in an HMM of  
 8 the channel;  
 9 selects state transitions between states  $S_t$  and  $S_{t+1}$  that corresponds to a largest  
 10  $L(S_t) = L(S_{t+1}) + m(\hat{I}_{t+1}(S_{t+1}))$ ; and  
 11 forms survivor state trajectories by connecting selected state transitions.

1 22. The decoder of claim 21, wherein the controller selects  $\hat{I}_t(S_t)$  that  
 2 corresponds to a survivor state trajectory at  $t = 0$  that has the largest  $L(S_t)$  as  $I_{1,p+1}^T$  for each  
 3 pth iteration, compares  $I_{1,p}^T$  and  $I_{1,p+1}^T$ , and outputs  $I_{1,p+1}^T$  as the second decode result if  $I_{1,p}^T$   
 4 and  $I_{1,p+1}^T$  are within the compare threshold.